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Improvement of mechanical properties of continuous fiber reinforced sand

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ABSTRACT: The improvement in the mechanical properties of the continuous fiber reinforced sand is investigated in terms of the shear strength and the resistance to the erosion. The improved reinforcement method using cement is applied to volcanic sandy soil, Shirasu, as well as ordinary sand, Kimitsu sand. It is found that the anisotropy of the fiber reinforced sand is not affected much by the cement content. The highest shear strength is obtained when the thread is arranged to be normal to the shear plane. With the increase in the cement content, the peak shear resistance increases and the shear deformation is decreased. The resistance against the erosion increases enormously by the cement content. Therefore, it is concluded that the mechanical properties of the reinforced sand are improved much by adding cement

1 INTRODUCTION

Continuous fiber reinforced sand, known as texsol, has been used for the construction of embankments, slope protections, retaining walls and so on. Multiple continuous fibers are mixed with sprayed sand by a water jet to improve the shear resistance of sand. Since the fibers are mixed with sand rather two-dimensionally in the plane of deposition, this composite material has strong anisotropy (Khay et al., 1990). Anisotropy of the fiber reinforced sand was investigated by simple shear tests as well as box shear tests (Kuwano et al., 1994). In the simple shear tests, the highest shear resistance was obtained when the angle of deposition was about 45° to 60°, in which direction the largest tensile strain was induced. The fibers need to be stretched enough to give sufficient confinement to the sample. The highest shear strength in the box shear test was obtained when the deposition angle was 90°.

Although the fiber reinforced sand has advantages of being greened, being reinforced rather uniformly along its height as compared to usual soil reinforcing techniques with geogrids and so on, it suffers from some points, e.g. certain amount of erosion occurs on the surface until it is covered with grass. Since sand particles are confined by fibers, it is expected that the reinforcement becomes more effective if the thread is tightly connected with sand. Kuwano et al. (1995) tried to improve the mechanical properties of the fiber reinforced sand with cement. It was found that the shear strength of the reinforced sand increased enormously by adding cement. The resistance against erosion was increased by cement content as reported by Akagi et al. (1992). In this paper, improvement of the mechanical properties of the fiber reinforced sand with cement is studied extensively. The improved reinforcement method is applied to volcanic sandy soil called Shirasu.

Table 1 Properties of thread

Material	Polyester
Thickness (D; Denier)	150(≒0.05mm)
Tensile strength / denier (mN/D)	43.5
Number of filaments(non-twisted)	30

2 TEST OUTLINES

Two types of sand were used for the tests. Kimitsu sand (D_{50}=0.38mm, Uc=2.75) is taken from Chiba Prefecture nearby Tokyo and is a type of sand usually used for the fiber reinforced sand. Shirasu (D_{50}=0.17 mm, Uc=12.88) is taken from Kagoshima Prefecture in Southern Kyushu. It is volcanic sandy soil which is composed of glassy and pumiceous fragments and is known as highly compressible sand in comparison with ordinary sand (Haruyama, 1987). Properties of thread are summarized in Table 1.

Three types of samples were prepared and tested. They are ST sample (sand+thread), SC sample (sand +cement) and STC sample (sand+thread+cement). Specimens were made in the laboratory by mixing pluviated sand with long polyester fibers through the use of water jet. Thread was spread uniformly over the plane of deposition by swinging the nozzle as schematically illustrated in Fig. 1. The amount of fibers mixed with sand was 0.2% by weight. 0.3% thread samples were also used in the test series of Shirasu. The reinforced sand was placed in the mold with the different deposition angle, α, of 0° to 180°, and compacted.

For the test series on cement improved sand, high-early-strength Portland cement was mixed with dry sand. Cement content was 3% or 5%. After the preparation of the specimen, the sample in the mold was cured for three days before the test.

Box shear tests were performed on reinforced sand samples. The specimen prepared in the mold as above was set in the shear box with the inner dimension of 30*30*30 cm as shown in Fig.2. It was consolidated and sheared under respective constant vertical stress, σ_v, at the shear displacement rate of 0.25mm/min.

The lower half of the specimen after the box shear test was utilized for the rainfall test. Since the erosion characteristics changed very little with α, most of the rainfall tests were carried out on α =0° samples. The specimen was set to have the slope of 45° as schematically shown in Fig.3. Artificial rain with the intensity of about 15mm/hr was poured from the height of 2m and the weight of eroded sand grains was measured.

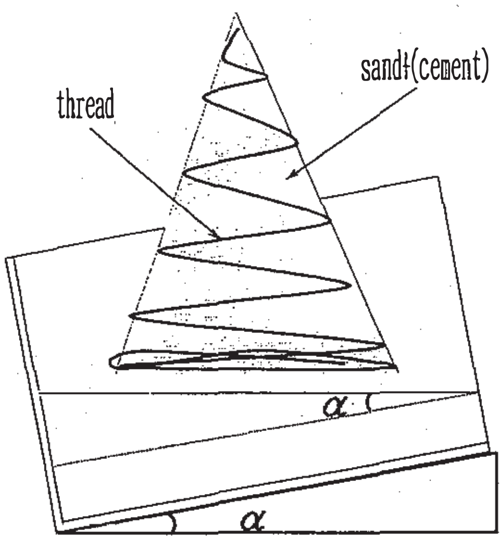

Fig.1 Sample preparation method

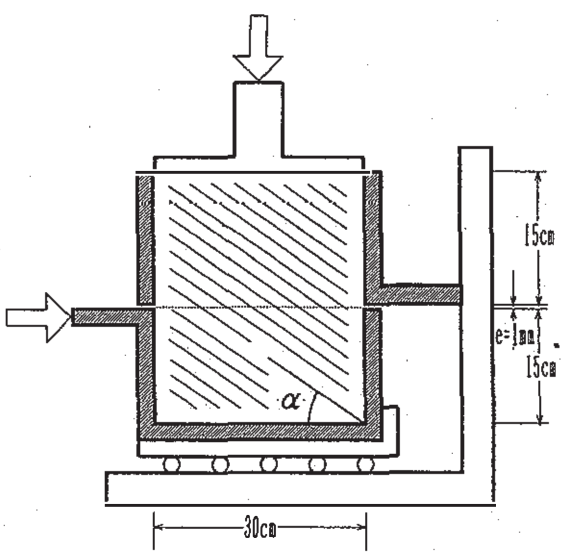

Fig.2 Box shear test on fiber reinforced sand

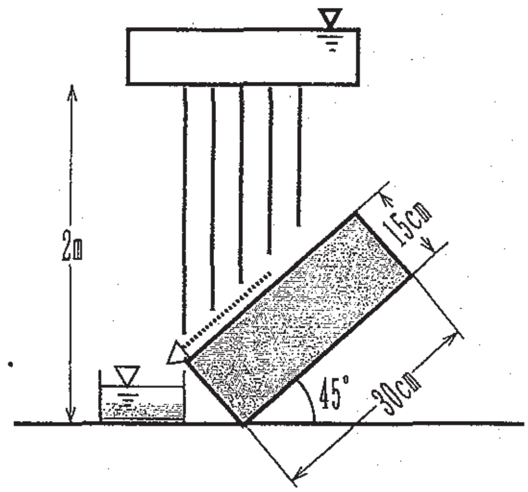

Fig.3 Rainfall test

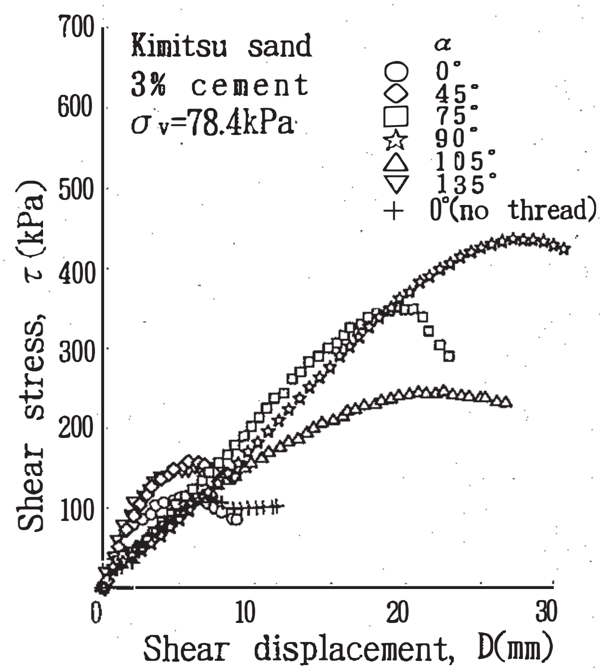

Fig.4 Shear stress vs. displacement of Kimitsu STC

3 BOX SHEAR TESTS

3.1 *Test results on Kimitsu sand*

Examples of box shear test results on Kimitsu sand with 0.2% thread and 3% cement are shown in Fig. 4 for the samples with different angle of deposition, α. It is seen in the figure that the shear stress-shear displacement relationship depends heavily on the deposition angle. The peak shear resistance of the sample with α=90° is highest, though the shear displacement to reach the peak strength is large. The peak strength of the specimen with α=0° is lowest

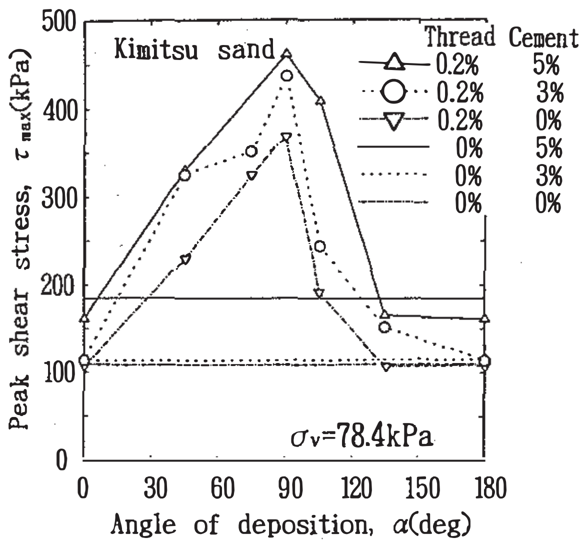

Fig.5 Variations in the shear strength with α

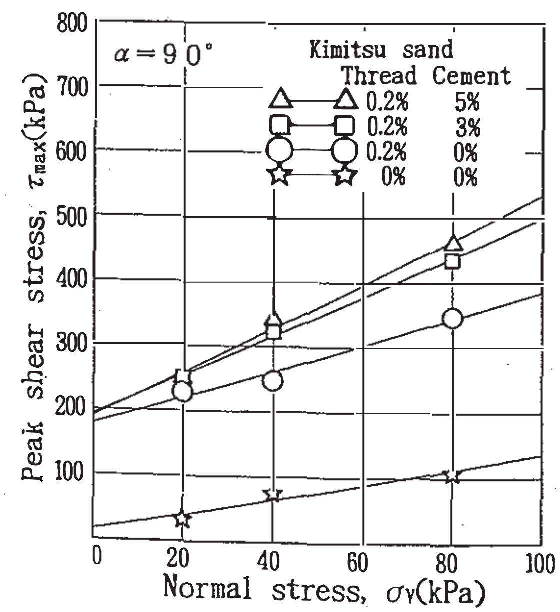

Fig.6 Variations in the shear strength with cement content (Kimitsu sand)

and is almost the same as that of the sample without thread. The shear stress-shear displacement curve of α=0° sample is almost the same as that of sand without thread, since the thread in α=0° sample is arranged in the direction of zero tensile strain in the shear box. In the case of α=45° sample, the initial slope of the curve is very steep, as the original direction of fibers is close to the direction of the largest tensile strain in the simple shear mode at the shear plane. The shear displacement at the peak shear stress is the largest when α=90°. In this case, certain amount of displacement is needed to rotate the thread to the direction of large tensile strain. The specimen in which the reinforcement by fibers plays major role in the shear resistance requires larger deformation, since they need to be stretched enough to bring sufficient confinement to the sample.

Variations in the shear strength, τ_{max}, with α are shown in Fig.5 for ST, STC(3%) and STC(5%) samples. They are similar in shape. The peak shear stress is highest at α=90° and the effect of fiber reinforcement is negligibly small at α=0° and 135°, irrespective of cement content. The anisotropy of the fiber reinforced sand seems not to be influenced much by the cement content.

Changes in the peak shear resistance with the vertical stress, σ_v, are shown in Fig.6 for α=90° samples with respective cement contents. It is seen in Fig.6 that the cohesion component of ST sample is considerably higher than that of pure sand sample, though the internal friction angles of them are almost the same. On the other hand, the internal friction angle as well as the cohesion component increases with cement content. The peak strength of the specimen containing 3% cement is as high as that of the sample with 5% cement.

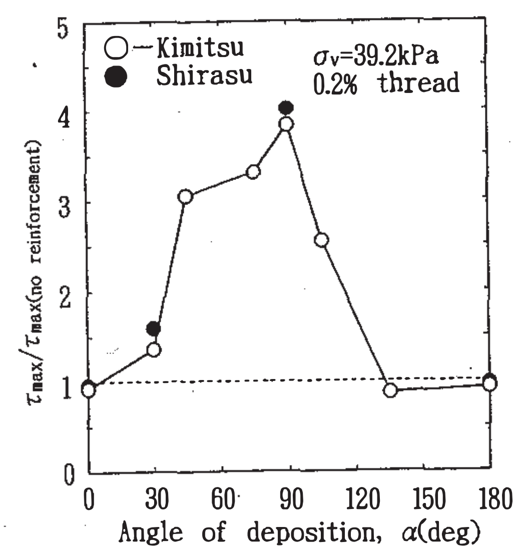

Fig.7 Reinforcement effects on Shirasu and Kimitsu

3.2 *Test results on Shirasu*

Box shear tests were carried out also on Shirasu, volcanic sandy soil. Variations in the shear strength, τ_{max}, with α were similar to those of Kimitsu sand. The highest peak shear stress was obtained when α =90°, i.e. the predominant direction of thread was normal to the failure plane. On the other hand, the sample with α=0°, i.e. the thread was arranged to be parallel to the shear plane, had the almost same shear strength as the sample without thread. Fig.7 shows the effect of fiber reinforcement on Shirasu and Kimitsu sand. In the figure, the peak shear strength of reinforced sand is normalized by that of sand without reinforcement. It is seen in the figure that Shirasu shows the similar variation of the strength with α, and is given almost the same reinforcement effect, as compared with Kimitsu sand.

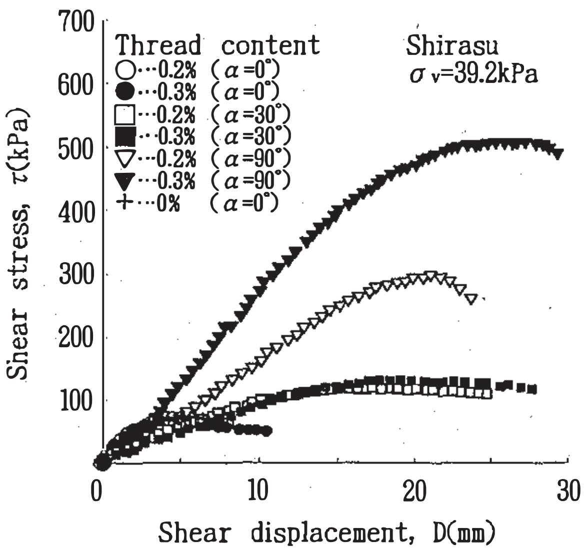

Fig.8 Effect of thread content on the shear resistance

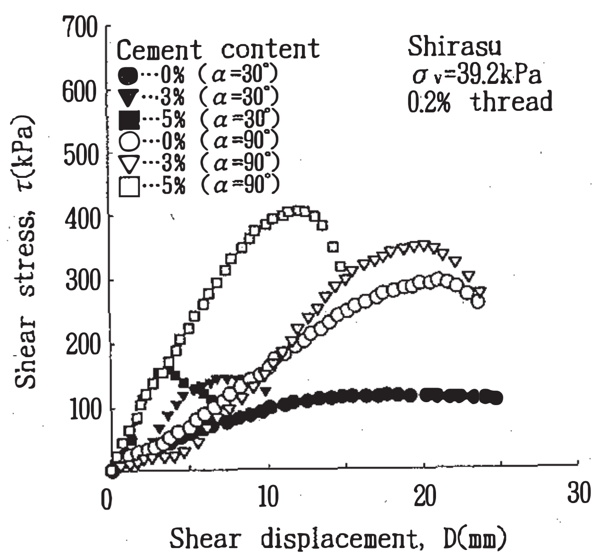

Fig.9 Effect of cement content on the shear resistance

Stress-displacement relationships of the samples with different thread contents and deposition angles are shown in Fig.8. It is seen that the shear resistance increases with the increase in the thread content, though it is clear only in the case of α =90° sample. The shear displacement is larger for the specimen with higher thread content. It is probably because the fibers need to be stretched enough to bring sufficient confinement to the sample in which reinforcement by fibers plays major role in the shear resistance as mentioned before.

Effect of cement content on the shear resistance is shown in Fig.9. The shear strength increases and the shear displacement at the peak shear stress decreases with the increase in the cement content. Although the slope at the initial part of the curve of ST sample or STC(3%) sample is rather gentle owing probably to disturbance, the slope at the middle part of the curve is steeper for the higher cement content.

Fig. 10 shows the shear stress-shear displacement curves of the STC samples (0.2% thread+5% cement) and ST samples (0.3% thread). Although the shear

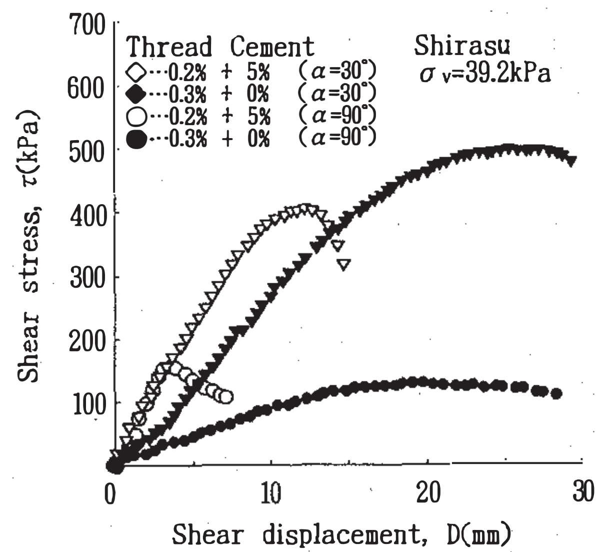

Fig. 10 Effects of thread and cement contents on the shear stress-displacement relationships of Shirasu

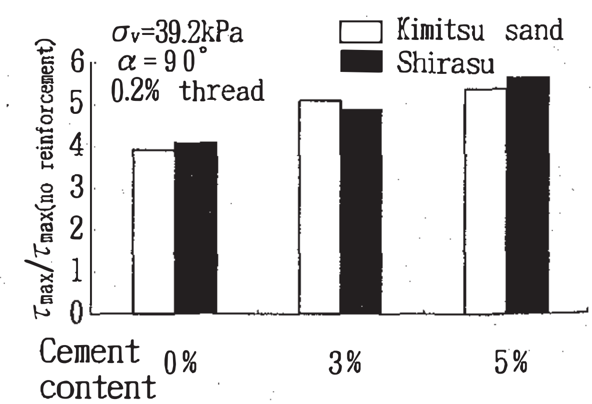

Fig. 11 Summary of the reinforcement effects

resistance of STC sample is higher than that of ST sample when $\alpha = 30°$, ST sample shows higher shear strength if the deposition angle is 90°. It indicates that even the 0.3% thread gives more reinforcement to the specimen than the 0.2% thread with 5% cement, since 90° is the deposition angle at which the confinement by fibers is given to sand most efficiently. The initial slopes of STC samples are steeper than those of ST sample irrespective of the deposition angle.

The reinforcement effect on Shirasu is summarized and compared with that on Kimitsu sand as in the form of Fig. 11 which indicates the ratios of the shear strength of the sample containing 0.2% thread to that of the specimen without thread for the respective cement contents. It is seen in the figure that the reinforcement effect on Shirasu is almost equivalent to that on Kimitsu sand.

4 RAINFALL TESTS

Accumulated weights of eroded Kimitsu sand are plotted against time for the respective types of the sample in Fig. 12. It is seen in the figure that the amount of erosion can be reduced just by mixing thread with sand probably because the fibers prevent sand particles from flowing down with water. It is to be seen in the figure that the amount of eroded sand is reduced to be the half when 5% cement is added to the sample. The amount of erosion of reinforced sand with 3% cement is as small as that with 5% cement.

Accumulated erosions of different types of Shirasu samples are shown in Fig. 13. The amount of erosion of pure Shirasu sample is enormously large because of its physical properties. It is as large as about 1kg, about 5% of the total weight of the specimen, after the 4 hr. rainfall. Considerable amount of erosion can be reduced by the higher fiber content. However, it seems to be more effective to use cement to reduce the erosion. The effect of mixing 5% cement only is nearly the same as that of mixing 5% cement and 0.3% thread.

The results of rainfall tests on Kimitsu sand and Shirasu are summarized in Fig. 14. It is seen that Shirasu is more susceptible to erosion than Kimitsu sand for the same conditions, i.e. the same thread content and the same cement content. However, if certain amount of cement is mixed with sand, the difference of erosion between two types of sand becomes small.

The ratios of amount of erosion of reinforced sand to that of sand without reinforcement are shown in Fig. 15 to see the effect of reinforcement to prevent the erosion. Since the amount of erosion of Shirasu without reinforcement is very large, it is found that the reinforcement is more effective to Shirasu than Kimitsu sand especially when some cement is mixed with Shirasu.

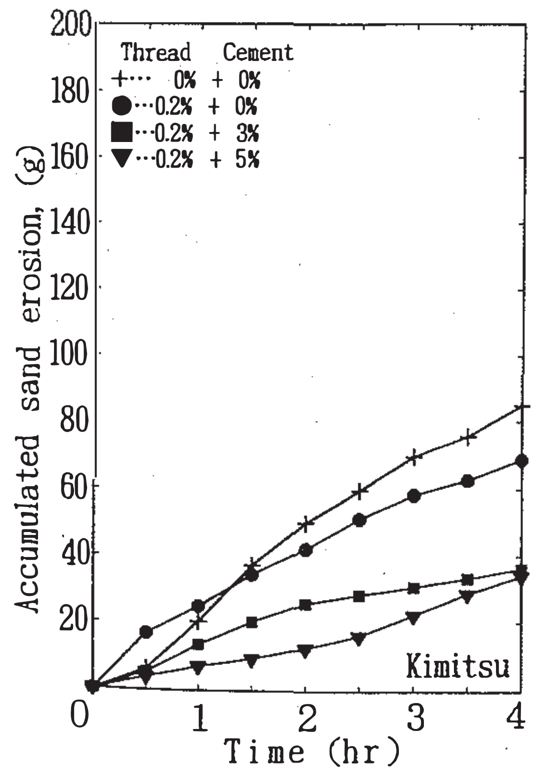

Fig.12 Accumulated weight of eroded Kimitsu sand

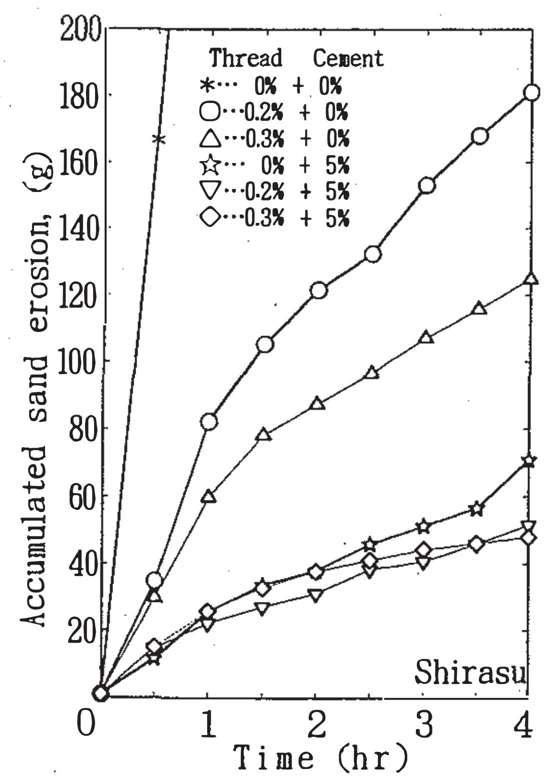

Fig. 13 Accumulated weight of eroded Shirasu

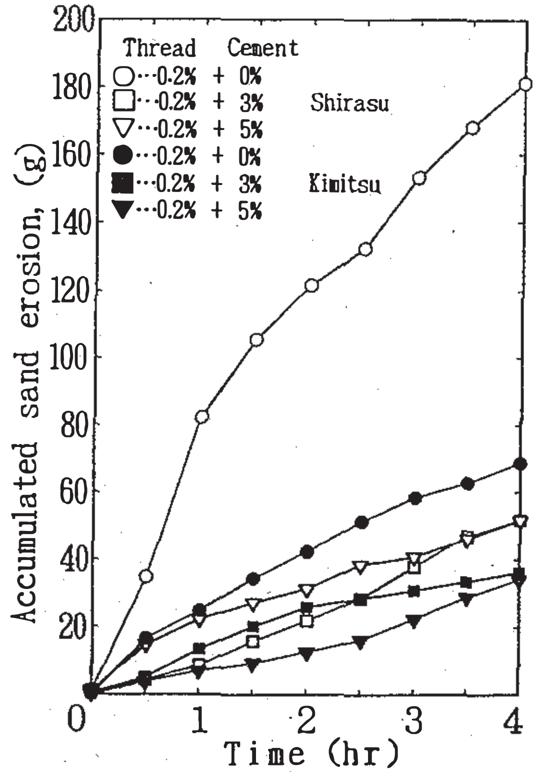

Fig.14 Accumulated weight of eroded STC sample

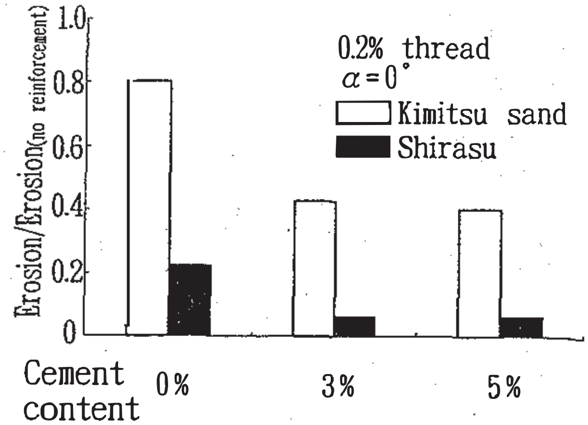

Fig.15 Effect of cement content on reducing erosion

5 CONCLUSIONS

From the box shear tests and the rainfall tests on fiber reinforced sand samples improved by cement, the following results were obtained.

1) The highest shear strength is obtained when α is 90° whether the sample is improved by cement or not. The anisotropy of the fiber reinforced sand is not influenced much by the cement content.

2) With the increase in the cement content, the peak shear strength increases and the shear deformation decreases.

3) The peak strength of the specimen containing 3% cement is as high as that of the sample with 5% cement.

4) Reinforcement effect on Shirasu is almost equivalent to that on Kimitsu sand.

5) The resistance against the erosion increases enormously by adding cement to the fiber reinforced sand. The effect of cement content is especially obvious in the case of Shirasu.

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